Damage tolerant aluminum alloy sheet for aircraft skin.

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Abstract

Disclosed is a method of producing a sheet product having improved levels of toughness and fatigue crack growth resistance while maintaining high strength, comprising providing a body of an aluminum base alloy containing 4.0 to 4.5 wt.% Cu, 1.2 to 1.5 wt.% Mg, 0.4 to 0.6 wt.% Mn, 0.12 wt.% max. Fe, 0.05 wt.% max. Si, the remainder aluminum, incidental elements and impurities and heating a body of the alloy to above 910 DEG F to dissolve soluble constituents. Thereafter, the body is hot rolled in the range of about 600 to 900 DEG F, solution heat treated for a time of less than about 15 minutes at a solution heat treating temperature, and rapidly cooled and naturally aged to provide a sheet product with improved levels of fatigue crack growth resistance while maintaining high strength.

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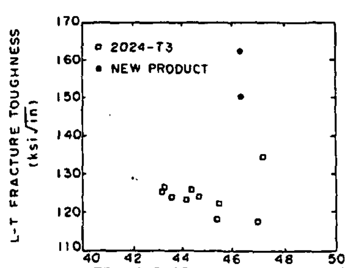
(54) Damage tolerant aluminum alloy sheet for aircraft skin.

(57) Disclosed is a method of producing a sheet product having improved levels of toughness and fatigue crack growth resistance while maintaining high strength, comprising providing a body of an aluminum base alloy containing 4.0 to 4.5 wt.% Cu, 1.2 to 1.5 wt.% Mg, 0.4 to 0.6 wt.% Mn, 0.12 wt.% max. Fe, 0.05 wt.% max. Si, the remainder aluminum, incidental elements and impurities and heating a body of the alloy to above 910°F to dissolve soluble constituents. Thereafter, the body is hot rolled in the range of about 600 to 900°F, solution heat treated for a time of less than about 15 minutes at a solution heat treating temperature, and rapidly cooled and naturally aged to provide a sheet product with improved levels of fatigue crack growth resistance while maintaining high strength.



STRENGTH VERSUS TOUGHNESS PLOT FOR NEW PRODUCT AND 2024-T3

FIG. 1

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This invention relates to aluminum alloys suitable for use in aircraft applications and more particularly, it relates to an improved aluminum alloy and processing therefor having improved resistance to fatigue crack growth and fracture toughness and suited to use as aircraft skin.

The design of commercial aircraft requires different sets of properties for different types of structures on the airplane. In many parts, resistance to crack propagation either in the form of fracture toughness or fatigue crack growth is essential. Therefore, many significant benefits can be realized by improving fracture toughness and fatigue crack propagation.

A new material with improved toughness, for example, will have a higher level of damage tolerance. On the aircraft, this translates to improved safety for passengers and crew and weight savings in the structure which allows for improved fuel economy, longer flight range, greater payload capacity or a combination of these.

Cyclic loading occurs on a commercial jet airplane during the take off/landing when the interior of the airplane is pressurized. Typically, airplanes may see up to 100,000 pressurization cycles during their normal service lifetime. Thus, it will be noted that great benefit is derived from improved fracture toughness and resistance to fatigue crack growth, both of which are related to cyclic loading.

U.S. Patent 4,336,075 discloses the use of AA2000 type aluminum alloy for aircraft wings.

The present invention provides aluminum base alloy sheet products and a method of fabricating sheet products from a body of the alloy. Further, the invention provides aluminum alloy sheet products suitable for aircraft applications such as wing skins and aircraft fuselage panels, which sheets may be clad with a corrosion protecting outer layer.

A principal object of the invention is to provide an aluminum alloy and sheet product formed therefrom, the sheet product having improved fracture toughness and resistance to fatigue crack growth while maintaining high strength properties and corrosion resistance.

A further object of the present invention is to provide aluminum alloy sheet products having improved fracture toughness and resistance to fatigue crack growth for aircraft panels.

Yet a further object of the present invention is to provide aluminum alloy sheet products and a process for producing the sheet products so as to provide improved fracture toughness and increased resistance to fatigue crack growth while still maintaining high levels of strength.

Still a further object of the invention is to provide a method for processing an aluminum alloy into clad sheet products having improved resistance to fatigue crack growth while maintaining high strength properties and corrosion resistance.

And still a further object is to provide an Al-Cu-Mg-Mn clad sheet product for use as aircraft panels such as wing or fuselage skins having improved resistance to fatigue crack growth while maintaining high strength levels and improved fracture toughness.

These and other objects will become apparent from a reading of the specification and claims and an inspection of the claims appended hereto.

In accordance with these object, there is provided a method of producing a sheet product having improved levels of toughness and fatigue crack growth resistance while maintaining high strength, the method comprising providing a body of an aluminum base alloy containing 4.15 to 4.5 wt.% Cu, 1.2 to 1.45 wt.% Mg, 0.4 to 0.7 wt.% Mn, 0.1 wt.% max. Fe, 0.1 wt.% max. Si, the remainder aluminum, incidental elements and impurities. The method further comprises heating a body of the alloy to above 900°F to dissolve soluble constituents. Thereafter, the body is hot rolled in the range of about 600 to 900°F, solution heat treated for a time of less than about 15 minutes, for example, at the solution heat treating temperature, then rapidly cooled and naturally aged to provide a sheet product with improved levels of fatigue crack growth resistance and fracture toughness while maintaining high strength levels.

Figure 1 shows fracture toughness plotted against yield strength of improved material processed in accordance with the invention.

Figure 2 is a graph showing fatigue crack growth rate plotted against crack length for Aluminum Association alloy 2024 in the solution heat treated, cold worked and naturally aged T3 temper (AA2024-T3) and the improved product in accordance with the invention.

Figure 3 is a differential calorimetry curve of 2024-T3.

Figure 4 is a differential calorimetry curve of an aluminum alloy product in accordance with the invention.

As noted, the alloy of the present invention comprises 4.0 to 4.5 wt.% Cu, 1.2 to 1.5 wt.% Mg, 0.4 to 0.7 wt.% Mn, 0.02 to 0.5 wt.% Fe, 0.001 to 0.5 wt.% Si, the balance aluminum, incidental elements and impurities. Impurities are preferably limited to 0.05% each and the combination of impurities preferably should not exceed 0.15%. The sum total of incidental elements and impurities preferably does not exceed 0.45%.

A preferred alloy would contain, 4.1 to 4.4 wt.% Cu, 1.2 to 1.45 wt.% Mg, 0.4 to 0.6 wt.% Mn, 0.1 wt.% max. Fe, 0.1 wt.% max. Si, the balance aluminum, incidental elements and impuriti s. Elements such as Zn preferably have a maximum of 0.2 wt.% and Cr 0.2 wt.% and 0.5 wt.% Zr, with a range for Zr being 0.05 to 0.25 wt.%, if it desired to make an unrecrystallized product. By unrecrystallized is meant that no more than 20 vol.% of the product is recrystallized. A typical alloy composition would contain about 4.25 wt.% Cu, 1.35 wt.% Mg, 0.5 wt.% Mn, 0.12 wt.% max. Fe and 0.1 wt.% max. Si with Fe plus Si not totaling more than 0.20 and preferbly not more than 0.15.

Mn contributes to or aids in grain size control during operations that cause the metal to recrystallize. Very large grains are detrimental to properties such as fracture toughness, formability and corrosion resistance.

Fe and Si levels are kept low to limit formation of the constituent phases Al_7Cu_2Fe and Mg_2Si which are detrimental to fracture toughness and fatigue crack growth resistance. These phases have low solubility in Al-alloy and once formed cannot be eliminated by thermal treatments. Formation of Al_7Cu_2Fe and Mg_2Si phases can also lower the strength of the product because their formation reduces the amount of Cu and Mg available to form strengthening precipitates. Constituents such as Al_7Cu_2Fe and Mg_2Si are particularly important to avoid because they cannot be dissolved; thus, iron is kept to a very low level to avoid such constituents. That is, a decrease in Fe and Si increases toughness and resistance to fatigue crack growth. Thus, in the present invention, it is preferred to control Fe to below 0.10 wt.% and Si below 0.10 wt.%.

Cu and Mg must be carefully controlled to maintain good strength while providing the benefits in toughness and fatigue. The Cu and Mg levels must be low enough to allow for dissolution of the slightly soluble Al_2CuMg and Al_2Cu constituent phases during high temperature processing yet high enough to maximize the amount of free Cu and Mg available to form the strengthening precipitate phases. This leaves a very narrow range of Cu and Mg compositions which will produce the desired properties in the final product.

The following equations may be used to estimate the "free Cu" and "free Mg"; that is, the amount of Cu and Mg that is available to form strengthening phases.

$$Cu_{Free} = Cu_{Total} - 2.28Fe - 0.74(Mn - 0.2)$$
$$Mg_{Free} = Mg_{Total} - 1.73(Si - 0.05)$$

As well as providing the alloy product with controlled amounts of alloying elements as described herein, it is preferred that the alloy be prepared according to specific method steps in order to provide the most desirable characteristics of both strength, fracture toughness, corrosion resistance and resistance to fatigue crack growth as required, for example, for use as aircraft skins or panels. The alloy as described herein can be provided as an ingot or slab for fabrication into a suitable wrought product by casting techniques currently employed in the art for cast products with continuous casting being preferred. Slabs resulting from belt casters or roll casters also may be used.

In a broader aspect of the invention, the alloy can comprise 3.8 to 4.5 wt.% Cu, 1.2 to 1.85 wt.% Mg, 0.3 to 0.78 wt.% Mn, 0.5 wt.% max. Fe, 0.5 wt.% Si, the balance aluminum, incidental elements and impurities.

The ingot or slab of the alloy of the invention may be provided with a cladding and then processed in accordance with the invention. Such clad products utilize a core of the aluminum base alloy of the invention and a cladding of higher purity alloy which corrosion protects the core. The cladding includes essentially unalloyed aluminum or aluminum containing not more than 0.1 or 1% of all other elements. However, Zn can be present as in AA7072, for example. Thus, the cladding on the core may be selected from Aluminum Association alloys 1100, 1200, 1230, 1135, 1235, 1435, 1145, 1345, 1250, 1350, 1170, 1175, 1180, 1185, 1285, 1188, 1199 or 7072.

The alloy stock may be homogenized prior to hot working or it may be heated and directly hot rolled. If homogenization is used, it may be carried out at a metal temperature in the range of 910 or 920°F to 960 or 1000°F for a period of time of at least 1 hour to dissolve soluble elements and to homogenize the internal structure of the metal. A preferred time period is about 4 hours or more in the homogenization temperature range. Normally, the soak time at the homogenizing temperature does not have to extend for more than 8 hours, however, longer times are not normally detrimental. 4 to 6 hours at the homogenization temperature has been found to be quite suitable. A typical homogenization temperature is 920°F.

For purposes of the present invention, it is preferred to hot roll the clad ingot without homogenizing. Thus, the ingot is hot worked or hot rolled to provide an intermediate gauge product. Hot rolling is performed wherein the starting temperature for rolling is in the range of 600 to 900°F. When the use of th alloy is for aircraft wing skins or fuselage skins, for example, the hot rolling is performed to provide an

intermediate product having a thickness of about 3 to 8 inches.

After hot rolling, the intermediate gauge product is subjected to a reheating step. It is this reheating step which is so important to the present invention, particularly with respect to minimizing or avoiding soluble constituent or secondary phase particles and their adverse effect on fatigue crack growth resistance and fracture toughness. Thus, in the reheating step, the intermediate gauge product is heated to a temperature of at least 900 or 920° F, e.g., above the solvus temperature of secondary phase particles, to dissolve soluble constituents that remain from casting or may have precipitated during the hot rolling. Such constituent particles include Al_2CuMg, Al_2Cu, for example. The reheating has the effect of putting most of the Cu and Mg into solid solution. The heating can be in the range of 900 to 945° F with a preferred range being 900 or 910 to 930° F. For purposes of reheating, the intermediate gauge product can be held for about 1 to 40 hours when the metal is in the temperature range or above the solvus temperature for the soluble constituents. Preferably, times at metal temperature are in the range of 4 to 24 hours. It is important that the reheat is carefully controlled within the parameters set forth. If the reheating operation is lower than 900° F, for example, 850° F, this can leave large volumes of coarse undissolved Al_2CuMg and Al_2Cu particles, for example, which particles can have an adverse effect on the fatigue crack growth resistance in the final product. In fact, if the reheat is below the solvus temperature, these particles can even grow in size. It is the presence of such constituent particles which can limit crack propagation resistance in the final sheet product.

In clad products, the temperature and duration of the reheat is very important for another reason. That is, if the time at reheat temperature is excessive, copper can diffuse into the higher purity aluminum cladding which can detrimentally affect the corrosion protection afforded by the cladding.

After the reheat, the intermediate product is subjected to a second hot rolling operation. The second hot rolling operation is performed in the temperature range of about 500 to 900° F, preferably 600 to 850° F. The hot rolling may be performed to a final gauge, e.g., 0.25 inch or less. Alternatively, the hot rolling step can be performed to provide a second intermediate product having a thickness in the range of 0.1 to 0.3 inch. Thereafter, the second intermediate product can be cold rolled to a final gauge of 0.25 inch or less, typically in the range of 0.05 to 0.20 inch, to produce a substantially recrystallized product. An intermediate anneal may be used before cold rolling, if desired.

After cold rolling, the sheet product is then subjected to a solution heat treatment in the range of 910 to 945° F. It is important that the solution heat treatment be carefully controlled in duration. Thus, the solution heat treatment can be accomplished in 5 minutes or even less when the metal has reached the solution temperature. The time can be extended to 15 minutes or even 60 minutes. However, in clad product, care should be taken against diffusion of copper into the cladding and possible problems resulting therefrom.

Solution heat treatment in accordance with the present invention may be performed on a continuous basis. Basically, solution effects can occur fairly rapidly. In continuous treating, the sheet is passed continuously as a single web through an elongated furnace which greatly increases the heat-up rate. Long solution heat treat times may be used to dissolve the soluble constituents such as Al_2CuMg and Al_2Cu. However, long time (more than 2 hours) solution heat treatments should not be used on clad products because of the excessive Cu diffusion that can occur in the cladding. The continuous approach facilitates practice of the invention since a relatively rapid heat-up and short dwell time at solution temperature result in minimizing copper dissolution into the cladding. Accordingly, the inventors contemplate solution heat treating in as little as about 10 minutes, or less, for instance about 0.5 to 4 minutes. As a further aid to achieving a short heat-up time, a furnace temperature or a furnace zone temperature significantly above the desired metal temperatures provides a greater temperature head useful to speed heat-up times.

After solution heat treatment, it is important that the metal be rapidly cooled to prevent or minimize the uncontrolled precipitation of secondary phases, e.g., Al_2CuMg and Al_2Cu. Thus, it is preferred in the practice of the invention that the quench rate be at least 100° F/sec from solution temperature to a temperature of 350° F or lower. A preferred quench rate is at least 300° F/sec in the temperature range of 925° F or more to 350° F or less. Suitable rates can be achieved with the use of water, e.g., water immersion or water jets. Further, air or air jets may be employed. Preferably, the quenching takes place on a continuous basis. The sheet may be cold worked, for example, by stretching up to 10% of its original length. Typically, cold working or its equivalent which produces an effect similar to stretching, may be employed in the range of 0.5% to 6% of the products' original length.

After rapidly quenching, the sheet product is naturally aged. By natural aging is meant to include aging at temperatures up to 175° F.

Conforming to these controls greatly aids the production of sheet stock having high yield strength, improved levels of fracture toughness, increased resistance to fatigue crack growth and high resistance to corrosion, particularly using the alloy composition of the invention. That is, sheet can be produced having a

minimum long transverse yield strength of 40 or 42 ksi, suitably minimum 44, 46 or 48 ksi, and a minimum fracture toughness of 140, 145 or 150 ksi $\sqrt{in}$. Also, the sheet has a fatigue crack growth rate of 10^{-4} inches per cycle at a minimum cyclic stress intensity range of 22 ksi $\sqrt{in}$.

Sheet fabricated in accordance with the invention has the advantage of maintaining relatively high yield strength, e.g., about 47 ksi, while increasing fracture toughness to about 150 to 165 ksi $\sqrt{in}$. Fracture toughness of the product in terms of measurements stated as K apparent (K app) using 16 inch wide panel can range from 88 or 90 to 100 ksi $\sqrt{in}$. As shown in Figure 2, the new product has considerably better resistance to fatigue crack propagation than existing fuselage skin alloys in tests conducted using a constant cyclic stress intensity factor range of 22 ksi$\sqrt{in}$. This cyclic stress intensity factor range is important for the damage tolerant design of transport airplanes such as commercial airliners.

Sheet material of the invention is characterized by a substantial absence of secondary phase particles, e.g., Al_7Cu_2Fe, Al_6(Fe, Mn) Al_2CuMg and Al_2Cu particles. That is, sheet material of the invention has generally less than 1.25 vol.% of such particles larger than 0.15 square µm as measured by optical image analysis through a cross section of the product.

That is, sheet material of the invention generally has a 500 to 530°C differential scanning calorimetry peak of less than 1.0 cal/gram. Figures 3 and 4 show a comparison between the new product and 2024-T3 which is the current material of choice for the fuselage skins of commercial jet aircraft.

Example

A 16 x 60 inch ingot having the composition 4.28% Cu, 1.38% Mg, 0.50% Mn, 0.07% Fe, 0.05% Si, balance Al was clad with AA1145 then heated to approximately 875°F and hot rolled to a slab gauge of 4.5 inches. The slab was then heated to a temperature above 910°F for 17 hours and hot rolled to a gauge of 0.176 inch. The metal was cold rolled to a final gauge of 0.100 inch before solution heat treating for 10 minutes at 925°F and stretching 1 to 3%. The sheet was aged for 3 weeks at room temperature.

For comparison, 2024-T3, which is currently used for the fuselage skins of commercial jet airliners, having the composition 4.6% Cu, 1.5% Mg, 0.6% Mn, 0.2% Fe, 0.2% Si, balance Al, was processed the same except it was not subjected to reheating at 910°F.

The product of the invention had a 16% higher plane stress fracture toughness ($K_c = 156.5$ ksi$\sqrt{in}$ average of new product data of Fig. 1 versus 134.7 ksi$\sqrt{in}$ average of highest two points of 2024 T-3 data of Fig. 1) and at a cyclic stress intensity range of 22 ksi$\sqrt{in}$ the cracks grew 44% slower ($da/dN = 5.3 \times 10^{-5}$ in/cycle versus 9.52×10^{-5} in/cycle) as shown in the table below. One possible explanation of the metallurgical causes of the improvement can be seen in Figures 3 and 4 which show differential scanning calorimetry curves. The size of the sharp peak that occurs in the temperature range of 500 to 530°C (Fig. 3) is indicative of the amount of constituent phase or phases such as Al_2CuMg and Al_2Cu present. These phases contribute to the lowering of fracture toughness and resistance to fatigue crack growth. The new product (Fig. 4) has a much smaller peak indicating that the volume fraction of such constituent has been significantly reduced in accordance with the present invention.

The volume fraction of total large constituent phase particles (including Fe and Si bearing particles), e.g., larger than 0.15 square pm, was much smaller for the new product than for the conventionally treated 2024-T3. In twelve measurements, the new product volume fraction ranged from 0.756% to 1.056%. In twelve measurements, the conventionally treated 2024-T3 constituent volume fraction ranged from 1.429% to 2.185%.

Fatigue Crack Propagation at
<u>Different Cyclic Stress Intensity Ranges</u>

Sample	ΔK	da/dN
New Product	10	6.70×10^{-6}
	22	5.30×10^{-5}
	30	1.34×10^{-4}
2024-T3	10	7.91×10^{-6}
	22	9.52×10^{-5}
	30	3.71×10^{-4}

ΔK=Cyclic Stress Intensity Factor Range
da/dN=Length of crack growth during one load/unload cycle
Test performed with a R-ratio (min. load/max. load) equal to 0.33.

Fracture toughness was measured using a 16-inch wide, 44-inch long panel. All values given were taken in the T-L orientation which means that the applied load was parallel to the transverse direction of the sheet and the crack propagated parallel to the longitudinal direction of the sheet. Fatigue crack growth resistance was measured as the length a crack propagates during each cycle at a given stress intensity range. The measurements were made with an R-ratio of 0.33 in the T-L orientation. It is readily seen that as the stress intensity factor increases, the extent of the improvement becomes more prominent.

Claims

1. A method of producing an aluminum base alloy sheet product such as for an aircraft skin particularly an aircraft wing or fuselage, having high strength levels and good levels of fracture toughness and resistance to fatigue crack growth comprising:
   (a) providing a body of an aluminum base alloy containing 4.0 to 4.5 wt% Cu, 1.2 to 1.5 wt.% Mg, 0.4 to 0.7 wt.% Mn, 0.5 wt.% max. Fe, 0.5 wt.% max. Si, the remainder aluminum, incidental elements and impurities;
   (b) hot rolling the body to a slab;
   (c) heating said slab to above 910°F to dissolve soluble constituents;
   (d) hot rolling the slab in a temperature range of 600 to 850 or 900°F to a sheet product;
   (e) solution heat treating;
   (f) cooling; and
   (g) aging to produce a sheet product having high strength and improved levels of fracture toughness and resistance to fatigue crack growth.

2. The method in accordance with claim 1 wherein the body is hot rolled in a temperature range of 600 to 900°F prior to said heating and/or the sheet product is cold rolled to a final sheet gauge such as 1.3 to 6.3mm (0.05 to 0.25 inch) after said hot rolling.

3. The method in accordance with claim 1 wherein:
   Cu is 4.1 to 4.5 wt.%;
   Mg is 1.2 to 1.4 wt.%;
   Mg is 1.2 to 1.45 wt.%;
   Fe is 0.12 wt.% max.; and/or
   Si is 0.1 wt.% max.

4. The method of claim 1, 2 or 3 wherein the body provided is a body of an aluminum base alloy containing 4.1 to 4.4 wt.% Cu, 1.2 to 1.45 wt.% Mg, 0.4 to 0.6 wt.% Mn, 0.12 wt.% max. Fe, 0.1 wt.% max. Si, the remainder aluminum incidental elements and impurities.

5. The method of claim 4, which comprises
   (e) solution heating treating for a time of less than 60 minutes in a temperatures range of 910 to 1050°F, preferably 910 to 945°F for less than 15 minutes; and

(f) rapidly cooling such as by being cold water quenched.

6. The method in accordance with claim 4, wherein the sheet is naturally aged.

7. The method according to any one of the preceding claims, which comprises
(c) reheating said slab to 910 to 945°F to dissolve soluble constituents.

8. The method in accordance with any one of the preceding claims, wherein said body of an aluminum base alloy has a cladding thereon of aluminum.

9. The method in accordance with claim 8, wherein the cladding is one of the following:
(i) it is of a higher purity aluminum alloy than said body;
(ii) the cladding is of the Aluminum Association AA 1000 series;
(iii) the cladding is of the Aluminum Association type AA1100, 1200, 1230, 1135, 1235, 1435, 1145, 1345, 1250, 1350, 1170, 1175, 1180, 1185, 1285, 1188, 1199 or 7072.

10. A damage tolerant aluminum base alloy sheet product e.g. an aircraft skin such as an aircraft wing or fuselage skin, having high strength and improved levels of fracture toughness and resistance to fatigue crack growth, the sheet comprised of an aluminum base alloy containing 4.0 to 4.5 wt.% Cu, 1.2 to 1.5 wt.% Mg, 0.4 to 0.6 wt.% Mn, 0.12 wt.% max. Fe, 0.1 wt.% max. Si, the remainder aluminum and incidental elements and impurities, the sheet having a minimum long transverse yield strength of 275 MPa (40 ksi [thousand pounds per square inch]), a minimum T-L fracture of 127 MPa $\sqrt{m}$ (140 ksi $\sqrt{in}$).

11. The sheet product in accordance with claim 10 wherein the alloy comprises 1.2 to 1.45 wt.% Mg and 0.1 wt.% max. Fe.

12. The sheet product in accordance with claim 10 having one or more of the following properties:
(i) the product has a minimum long transverse yield strength of 44 ksi;
(ii) the sheet has a minimum long transverse yield strength of 42 ksi;
(iii) the product has a minimum T-L fracture toughness of 131 MPa$\sqrt{m}$ (144 ksi $\sqrt{in}$);
(iv) the product has a T-L fatigue crack growth rate of 2.5 x 10^{4}cm (10^{-4} inches per cycle at a minimum cyclic stress intensity range of 20 MPa$\sqrt{m}$ (22 ksi $\sqrt{in}$);
(v) the product has a volume fraction of particles including $A1_2CuMg$ and $A1_2Cu$ less than 1.25 vol.% larger than 0.15 square μm;
(vi) the product has a volume fraction of particles including $A1_2CuMg$ and $A1_2Cu$ less than 1 vol. % larger than 0.15 square μm;
(vii) the product has a thickness of 0.05 to 0.25 inch;
(viii) the product was solution heat treated, quenched and naturally aged;
(ix) the product is recrystallized.

13. The sheet product in accordance with any one of claims 10 to 12 wherein the aluminum base alloy sheet has a cladding thereon of aluminum.

14. The sheet product in accordance with claim 13, wherein the cladding is one of the following:
(i) sheet has a cladding of aluminum thereon of the Aluminum Association AA1000 series;
(ii) cladding of aluminum of the Aluminum Association alloys AA1145, 1230, 1060 or 1100.

15. A method of producing an aluminum base alloy sheet product e.g. an aircraft skin such as an aircraft wing or fuselage skin, having high strength levels and good levels of fracture toughness and resistance to fatigue crack growth comprising:
(a) providing a body of an aluminum base alloy containing 3.8 to 4.5 wt.% Cu, 1.2 to 1.85 wt.% Mg, 0.3 to 0.78 wt.% Mn, 0.5 wt.% max. Fe, 0.5 wt.% max. Si, the remainder aluminum, incidental elements and impurities;
(b) hot rolling the body to slab;
(c) heating said slab to above 910°F to dissolve soluble constituents;
(d) hot rolling the slab in a temperature range of 600 to 900°F to a sheet product;
(e) solution heat treating;
(f) cooling; and

(g) aging to provide a sheet product having high strength and improved levels of fracture toughness and resistance to fatigue crack growth.

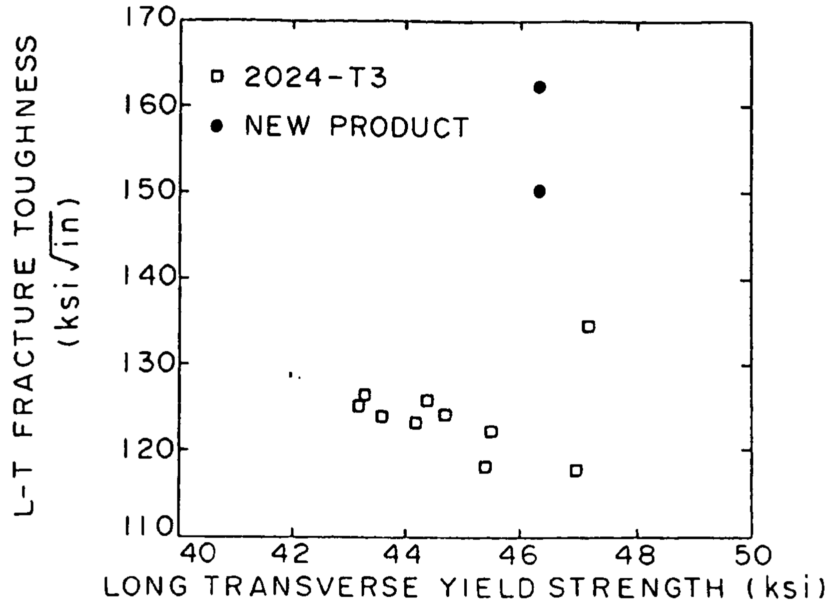
16. The method of claim 15, which comprises:
(b) hot rolling the body to a slab in a temperature range of 600 to 900°F prior to said reheating.

17. The method of claim 15, which comprises:
(d) hot rolling the slab in a temperature range of 600 to 850°F to a sheet product.

18. The method of claim 15, which comprises one or more of the following:
(i) solution heat treating for a time of less than 60 minutes, preferably less than 15 minutes, in a temperature range of 910 to 1050°F; and
(ii) rapidly cooling;
(iii) the sheet product is cold rolled to a sheet gauge having a thickness in the range of 1.3 to 6.3 mm (0.05 to 0.25 inch) after said hot rolling;
(iv) said aging is naturally aging.

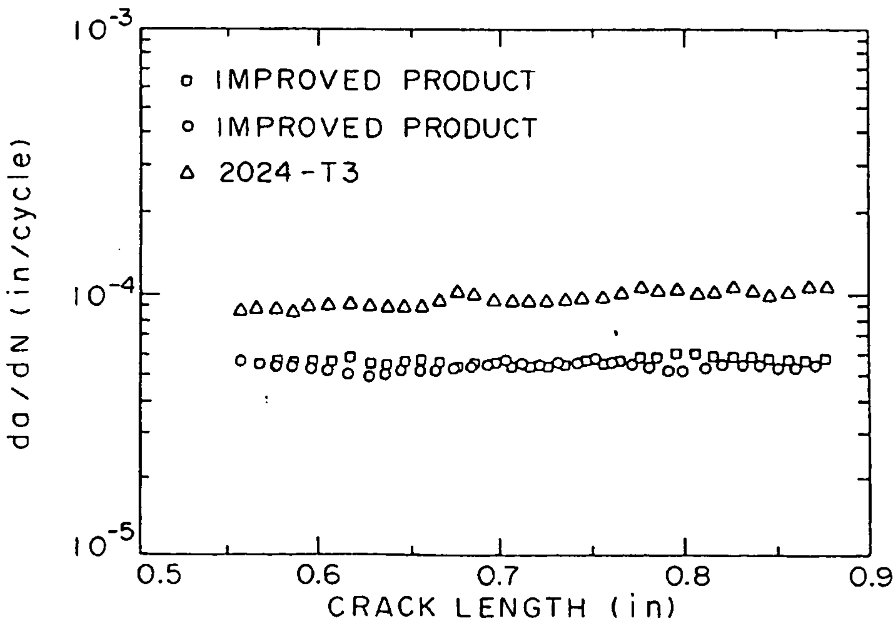
19. The method of any one of claims 15 to 18 wherein said body has a cladding thereon of aluminum.

20. The method of claim 19, wherein said cladding is one of the following:
(i) a cladding of aluminum thereon of the Aluminum Association AA1000 series;
(ii) cladding thereon of the Aluminum Association alloys AA1100, 1200, 1230, 1135, 1435, 1145, 1345, 1250, 1350, 1170, 1175, 1180, 1185, 1285, 1188, 1199 or 7072.



STRENGTH VERSUS TOUGHNESS PLOT
FOR NEW PRODUCT AND 2024-T3

FIG.1



FATIQUE CRACK GROWTH RATE VS CRACK LENGT
FOR 2024-T3 AND THE IMPROVED PRODUCT
ΔK 22 ksi$\sqrt{in}$, R=0.33, T-L ORIENTATION

FIG.2

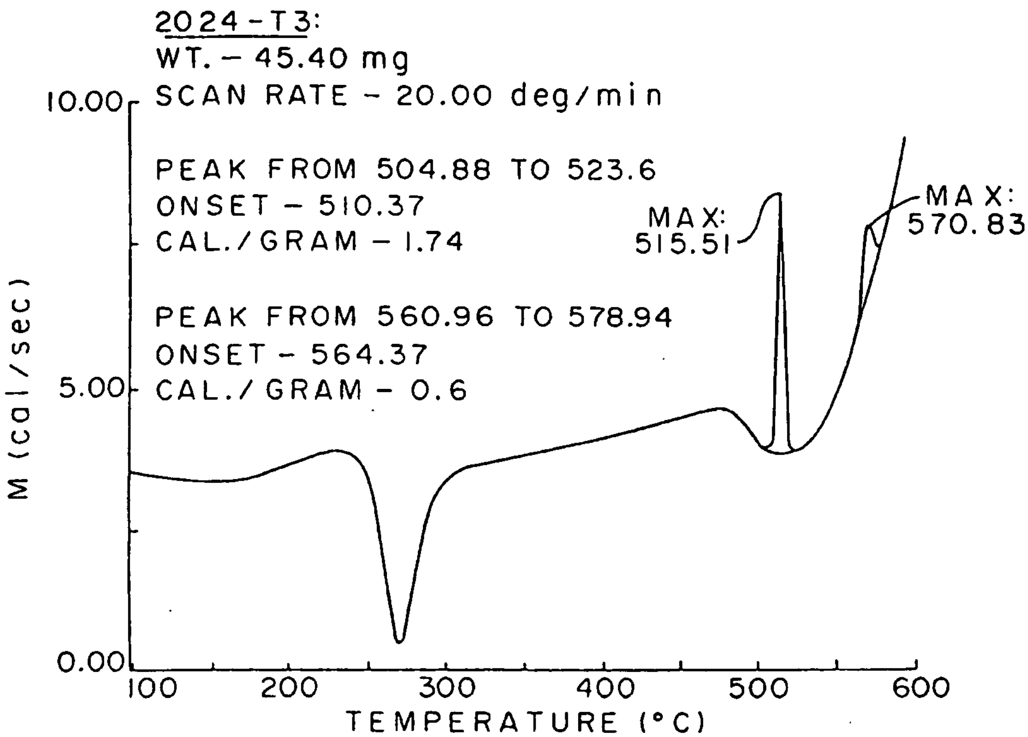

2024-T3:
WT. – 45.40 mg
SCAN RATE – 20.00 deg/min
PEAK FROM 504.88 TO 523.6
ONSET – 510.37
CAL./GRAM – 1.74
PEAK FROM 560.96 TO 578.94
ONSET – 564.37
CAL./GRAM – 0.6
MAX:
515.51
MAX:
570.83
10.00
5.00
0.00
M (cal/sec)
100
200
300
400
500
600
TEMPERATURE (°C)

FIG. 3

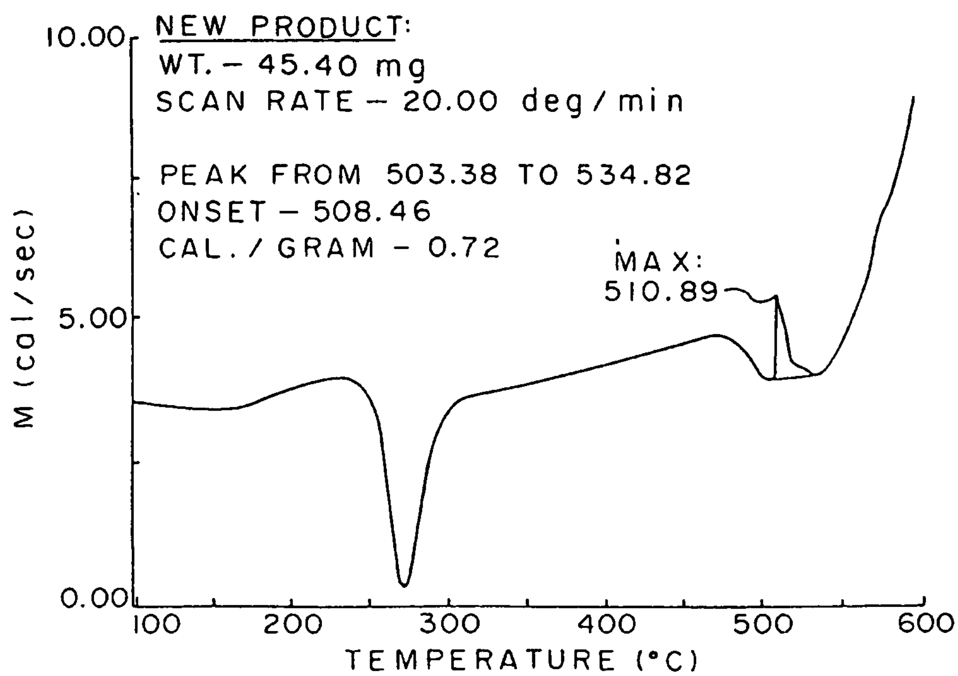

NEW PRODUCT:
WT. – 45.40 mg
SCAN RATE – 20.00 deg/min
PEAK FROM 503.38 TO 534.82
ONSET – 508.46
CAL./GRAM – 0.72
MAX:
510.89
10.00
5.00
0.00
M (cal/sec)
100
200
300
400
500
600
TEMPERATURE (°C)

FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 11 4388

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	EP-A-0 038 605 (THE BOEING CO.) * Claim 1; example 1 *	1,10,15	C 22 F 1/057 C 22 C 21/16 // B 32 B 15/01
A	GB-A-1 122 912 (ALUMINIUM CO. OF AMERICA) * Claims 1,10,15 *	1,10,15	
A	"Metals Handbook", vol. 2, "Properties and selections: non-ferrous alloys and pure metals", 9th edition, 1979, pages 50,72-75, American Society for Metals, Metals Park, Ohio, US * Page 50, centre-column, last paragraph - right-hand column, paragraph 1; page 73, last line - page 74, left-hand column, line 9 *	8,9,13,14, 19,20	
A	J.E. HATCH: "Aluminium", vol. 1, "Properties and physical metallurgy", 1st edition, 1984, pages 267-267,361-365,372-374, American Society for Metals, Metals Park, Ohio, US		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

C 22 F
C 22 C
B 32 B

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	05 November 91	GREGG N.R.

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
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